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The impact of mergers in the mass distribution of white dwarfs

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Abstract. Recent surveys have allowed to derive the white dwarf mass distribution with reasonable accuracy. This distribution shows a noticeable degree of structure that it is often attributed to the evolution of close binaries in general, and to mergers in particular. To analyze if the origin of this structure can be attributed to the merger of double white dwarfs, we have used a simplified population synthesis model that retains the essential processes of formation of double degenerate binaries. Special care has been taken to avoid artifacts introduced by discontinuities in the distribution functions. Our result is that these structures are not probably due to mergers, but they can provide a deep insight on the evolution of close binary systems.

1. Introduction

White dwarfs are the most common stellar remnants of the Galaxy, and a good fraction of them are members of binary systems. A recent study of the local neighborhood (Holberg et al. 2008) has shown that the $\sim$ 25% of the white dwarfs within 20 pc from the Sun are in binary systems and that approximately $\sim$ 6% of them are double white dwarfs (DD systems). Because of the emission of gravitational waves, close enough degenerate pairs loose angular momentum and eventually will merge.

The process of merging has been modeled by several groups using SPH techniques (Benz et al. 1990; Rasio & Shapiro 1995; Segretain et al. 1997; Guerrero et al. 2004; Yoon et al. 2007; Lorén-Aguilar et al. 2009) or grid-based techniques (D'Souza et al. 2006; Motl et al. 2007). Both sets of simulations suggest that there is not a prompt explosion after the coalescense and that a rotating hot corona surrounded by a thick disk form around the most massive white dwarf. The amount of matter lost during this process is very small (Guerrero et al. 2004) but the subsequent evolution of this structure is rather uncertain due to the difficulties introduced in modelling by the different time scales involved in the process. The key issue in determining the outcome of the interaction is the rate and the total mass accreted by the primary after the merger, and this strongly depends on the coupling between the rotating star, the disk and the magnetic

fields that contribute to the transport of angular momentum (Piersanti et al. 2003a,b; Saio & Nomoto 2004; Shen et al. 2012)

It is generally accepted that if the merging white dwarfs are made of carbon and oxygen, their total mass is larger than Chandrasekhar's mass, and no mass is ejected from the system, the final object would eventually collapse to form a neutron star (Nomoto & Kondo 1991) or explode as a Type Ia supernova (Webbink 1984; Iben & Tutukov 1984). If the final mass is smaller than the critical mass, either because the mass losses from the disk are large enough, or because the initial total mass was initially smaller, the final outcome is a new, more massive and probably peculiar white dwarf. This scenario has been invoked to account for the existence of bright massive white dwarfs in the halo, the presence of dusty disks around white dwarfs with metal-rich atmospheres (García-Berro et al. 2007), to explain R Corona Borealis stars (Webbink 1984; Longland et al. 2011) or strong-field magnetic white dwarfs (García–Berro et al. 2012). In the case of the merging of a CO and a He white dwarf, the outcome can be a thermonuclear explosion (Nomoto 1982) or a white dwarf with a mass equal or smaller than the total initial mass. Finally, if both white dwarfs are made of He, the final outcome would be the destruction of the object, or the formation of a new white dwarf.

At present, there are several deep surveys that have provided the necessary data to compute reliable white dwarf mass functions: the Palomar Green survey (Liebert et al. 2005), the SDSS (Kepler et al. 2007; De Gennaro et al. 2008) and the recent analysis of the solar neighborhood of Giammichele et al. (2012). These mass functions display some degree of structure as compared with what should be expected from the evolution of single white dwarfs. Besides the typical main peak (Koester et al. 1979), the most important features are the presence of a low-mass population — that is usually attributed to the evolution of close binaries — an excess of stars with masses ranging from 0.8 to 1.1 $M_\odot$, and a possible peak around 1.2 $M_\odot$. These features are usually attributed to white dwarf mergers (Marsh et al. 1997), although they are strongly affected by selection effects (Liebert et al. 2005).

2. Method of calculation

In this work we use a simple toy model to follow the evolution of the populations of single and binary white dwarfs. Our simulations aim to predict the expected number of DD mergers (Isern & et al. 1997). To compute the distribution of double degenerate binaries it is necessay to use a code able to examine, case by case, the final outcome of all the initial configurations. Since we are only interested in the impact of the mergers of DD systems on the mass distribution of white dwarfs, we have only considered the situations in which Roche lobe overflow occurs when the envelope of the star is convective and when magnetic braking is effective.

The evolution of a binary system which experiences a common envelope phase is still plagued with uncertainties. Here we assume that the orbital energy is invested in evaporating the common envelope (Iben & Tutukov 1984) in such a way that the new separation after the common envelope phase is given by:

$$A' = \alpha \frac{M_{1\mathrm{r}} M_2}{M_1^2} \tag{1}$$

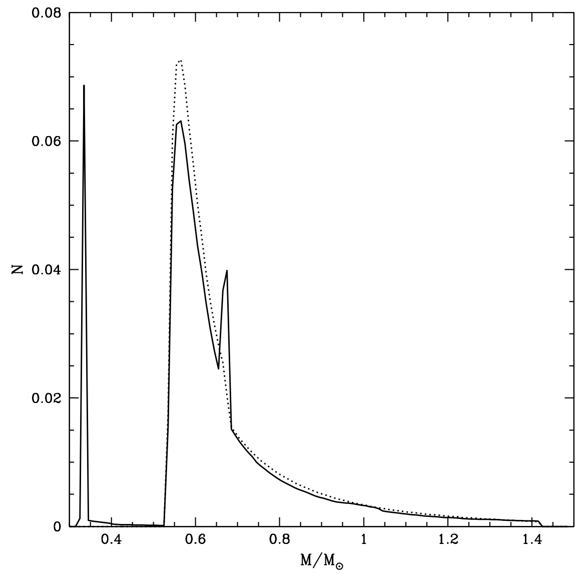

Figure 1. Normalized mass distributions of single white dwarfs (dotted line) and single plus binary white dwarfs (solid line) assuming that all the stars belonging to binary systems have known masses.

where α is a dimensionless free parameter that describes the efficiency of the energy transfer, $M_{1\rm r}$ is the mass of the remnant, M_1 is the original mass of the primary, M_2 is the mass of the secondary and A is the initial separation. Since the value of α is not known, we have adopted $\alpha = 1$, although different values and functional dependences have also been investigated.

Concerning the collective properties of binaries necessary to perform the calculations, we have adopted the following ones: i) The initial mass function is written as the mass distribution of the primary times the mass ratio distribution (Yungelson et al. 1993), while the mass distribution of the primary star is taken to be a simple Salpeter's distribution in the range $0.1 \leq M_1/M_\odot \leq 100$ and the mass ratio distribution as $f(q) \propto q^n$, where $q = M_2/M_1$ with $n = 1$. ii) The adopted distribution of separations is $H(A_0) = (1/5)\log(R_\odot/A_0)$ and, in order to maximize the impact of mergers in the mass distribution function, we assumed that single white dwarfs are well represented by the distribution of wide binaries (Yungelson et al. 1993). iii) It is also assumed a constant star formation rate, although several exponentially-decreasing formation rates with different time scales have also been considered. iv) The age of the Galactic disk is taken to be 10.5 Gyr, but values as high as 13 have also been considered. v) The influence of metallicity on the age of the progenitors and the mass of the resulting white dwarf has been neglected, and it is assumed that all white dwarfs more massive than 1.05 $M_\odot$ are made of oxygen and neon. vi) We have also assumed that all the binary systems are resolvable in mass.

The stellar data for the white dwarf progenitors is taken from Dominguez et al. (1999) and the adopted relationship between the mass of the progenitor and the mass

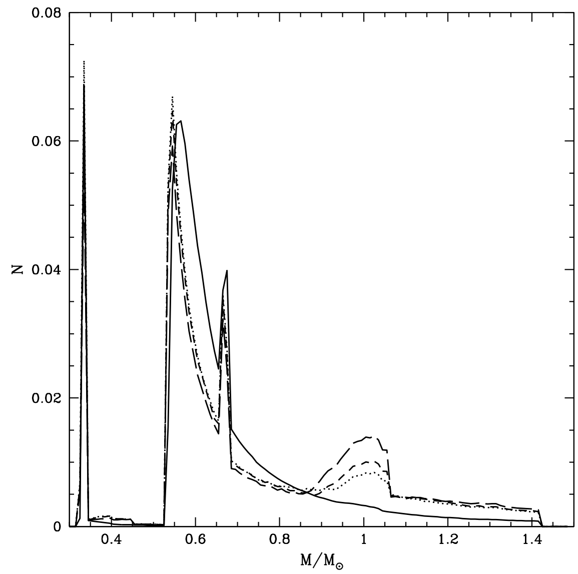

Figure 2. Mass distributions of cold and hot binary white dwarfs. The solid line represents the mass distribution of all white dwarfs while the broken ones those of hot white dwarfs. White dwarfs hotter than 15,000, 13,000 and 12,000 K are represented by the long-dashed, dashed and dotted lines respectively.

of the resulting white dwarf is that of Catalán et al. (2008). The cooling times are from Serenelli et al. (2002) for He white dwarfs, from Salaris et al. (2000, 2010) for CO white dwarfs and from Althaus et al. (2007) for the ONe white dwarfs. In these calculations it is assumed that after merging, the new white dwarf has the same initial temperature and chemical composition as white dwarfs of the same mass born from a single star.

3. Results and discussion

Fig. 1 displays how the mass function of white dwarfs changes when the evolution of binaries is included (solid line) or not (dotted line). The first noticeable difference is the presence of a narrow spike at $\sim 0.30\,M_{\odot}$, which is entirely due to the presence of He white dwarfs in binary systems. This is a well known result and its extreme thinness is probably caused by the simplicity of the model used here. The main peak of the distribution is smaller than in the case in which binaries are not taken into account due to the fact that in many binaries CO white dwarfs cannot form. The secondary peak appearing at $\sim 0.7\,M_{\odot}$ is caused by the merger of two He white dwarfs and is a consequence of the assumption that these objects evolve to form a CO white dwarf. Therefore, the properties of this peak, including its absence, could provide important insights into the process of merging of such objects. The region above this peak is rather smooth and is characterized by the fact that for $M_{\rm WD} \lesssim 1\,M_{\odot}$ the number of white dwarfs in the case in which binaries are considered is systematically smaller than

in the simulation in which are not, while for $M_{\rm WD} \gtrsim 1\,M_\odot$ this is not case. This effect is caused by mergers, but its influence is small (at $1\,M_\odot$ CO+He mergers represent $\sim 17.7\%$ of all white dwarfs and CO+CO mergers $\sim 5.5\%$), so there is not any prominent bump.

In order to compare with the observations it is necessary to take into account that the mass distribution is only known for DA white dwarfs with $T_{\rm eff} \gtrsim 12\,000 - 13\,000$ K. This is due to the fact that hotter white dwarfs can contain important amounts of helium in their atmospheres, which makes the determination of their mass unreliable (Bergeron et al. 1992; Giammichele et al. 2012). Fig. 2 compares the mass distribution function of hot white dwarfs (dashed and dotted lines) with that of all white dwarfs (solid line). The most noticeable feature is the prominet bump around $1\,M_\odot$. It is clear that this behavior is not caused by the mergers but by the dependence of the cooling rates with the mass. Moreover, this bump is not present in the mass distribution obtained from the SDSS catalogue, but it appears in the mass distribution of nearby stars.

4. Conclusions

Our toy model indicates that effectively the interaction of stars in close enough binary systems can introduce important changes in the expected mass distribution of white dwarfs resulting from the evolution of single stars. Besides the existence of He white dwarfs, the merging of such stars can produce a pronounced bump around $0.7 - 0.8\,M_\odot$. The exact location and shape of this bump depends on the details of the merging process. The merger of CO and He and of two CO white dwarfs only introduces small variations in the mass distribution. In the case of hot white dwarfs we have found a bump at $\sim 1 M_\odot$ caused by the dependence of the cooling rate on the mass of the white dwarf. This bump is absent in the mass function obtained from the SDSS catalogues but there is a hint of it in the mass function of the local sample.

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